

Final Report for ONR Grant N00014-01-1-0140
Analysis of Observations from the Coastal Mixing and Optics Moored Array

Steven J. Lentz and R. Kipp Shearman, M.S. 21

Woods Hole Oceanographic Institution

Department of Physical Oceanography

Woods Hole, MA 02543

web site <http://uop.whoi.edu/pub/uopcmo.html>

Long-Term goals:

Our long-term goal is to identify and understand the dominant vertical mixing processes influencing the evolution of the stratification over continental shelves.

Objectives:

Our objective is to understand the processes influencing the observed evolution of the stratification over the New England shelf during the Coastal Mixing and Optics program. We are particularly interested in the relative contributions of local, one-dimensional mixing processes, such as wind forced mixing, cooling, and tidal mixing versus three dimensional advective effects.

Approach:

Analysis of observations from a moored array of instruments deployed at a mid-shelf location in the Mid-Atlantic Bight from August 1996 through June 1997. The deployment spanned the destruction of the thermal stratification in fall and redevelopment of the stratification in spring and included currents, temperature and conductivity measurements spanning the water column and meteorological measurements to estimate surface fluxes.

Work Completed:

A manuscript characterizing the temperature/salinity variability and the processes responsible for that variability during CMO has accepted for publication in *Journal of Geophysical Research*. A manuscript characterizing the subtidal current variability and the associated dynamics has been submitted to *Journal of Geophysical Research* and is now in revision. A manuscript on the climatology of salty intrusions within the Middle Atlantic Bight has been submitted to *Journal of Geophysical Research*. A manuscript comparing five current meters deployed in Buzzards Bay has been submitted to *IEEE Journal of Ocean Engineering*. Manuscripts on 1) the tidal and supratidal current variability, and 2) the heat and salt balances during CMO are near completion.

Results:

The seasonal thermocline was well established on the New England shelf in August. The destruction of the seasonal thermocline during the fall resulted in an essentially unstratified water column in late November and early December. During the winter, the water column was stratified near the bottom due to the onshore movement of warm, salty, shelf-slope front water. In spring, stratification developed in the upper water column due to both the reestablishment of the seasonal thermocline and the presence of buoyant low-salinity water in the upper 20 m. Four processes contributed to these variations. 1) The breakdown of stratification was primarily due to wind forcing, not surface cooling, and occurred in four discrete steps associated with westward, along-coast wind stress events. Eastward wind stresses of similar magnitude did not

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reduce the stratification. 2) The on-offshore movement of the foot of the shelf-slope front throughout the deployment was, at least in part, wind-driven. The water column at mid shelf remained stratified throughout most of the winter due to the onshore displacement of shelf-slope front water forced by anomalously strong and persistent eastward wind stresses. 3) The gradual redevelopment of the thermocline, beginning in April, was primarily a one-dimensional response to the increasing surface heat flux. 4) Stratification in early April and throughout May was substantially enhanced by low-salinity water associated with river runoff from southern New England, notably the Connecticut River. This low-salinity water was driven eastward and offshore by upwelling-favorable wind stresses.

Subtidal current variability over the New England shelf during the CMO experiment is large (10 cm/s standard deviation). Subtidal variability on 2-10 day time scales was polarized alongisobath, and strongly correlated with alongcoast wind stress variability. The alongcoast direction is determined by the coastline orientation on length scales larger than 1000 km, matching approximately the scale of storms, a major source of subtidal wind stress variability. On monthly and longer time scales, along-isobath currents are related to fluctuations in the cross-isobath density gradient and not wind stress. During the fall, cross-isobath density gradients are strongest due to a reversal of the cross-isobath temperature gradient that is potentially related to seasonal heating.

Tidal, inertial and higher-frequency current variability constitutes approximately 50% of the of the total current variability during the CMO experiment. Tidal currents are predominantly semidiurnal, barotropic and increase in magnitude onshore and toward the east. Near the bottom, tidal current amplitude decreases rapidly and phase increases, consistent with the presence of mixing in a tidally-driven bottom boundary layer. Semidiurnal current shear near the bottom increases linearly with variations in near bottom stratification on weekly to monthly intervals. Baroclinic tides are small. Analysis of current meter records from CMO, NSF (Nantucket Shoals Flux Experiment) and the SEEP (Shelf Edge Exchange Processes) study with the barotropic tide removed indicates a distinct seasonal cycle to baroclinic tidal current variability with low (< 1 cm/s standard deviation) variability during the winter unstratified period and high (2-3 cm/s standard deviation) during the summer stratified period. Also, baroclinic tidal variability increases offshore. During CMO, baroclinic tidal variability is characterized by the first baroclinic mode with a zero-crossing near 30 m, and is in phase with the barotropic tide below 30 m. Inertial band current variability, during CMO, is predominantly baroclinic (mode 1) and increases in magnitude offshore. Like the baroclinic tidal variability, inertial variability is stronger during the stratified period, although the relation is not linear. During the fall, near-inertial current variability occurs at subinertial frequencies (identified by wavelet analysis), while during the spring, near-inertial variability occurs at or above the local inertial (Coriolis) frequency (f). The frequency variation is linearly related to variations in the effective Coriolis frequency which incorporates the effect of subtidal relative vorticity on planetary vorticity. In the fall during CMO, subtidal relative vorticity is large and anticyclonic ($-0.05f$ on average).

Intrusions of anomalously salty (and typically warm) water from the slope are often found over the continental shelf of the Middle Atlantic Bight and were observed on several occasions during CMO. These salty intrusions (often referred to as Smax intrusions) represent a potentially important mechanism of shelf-slope exchange. Historical hydrographic data archived by NODC

was analyzed to determine the distribution and characteristics of salty intrusions over the Middle Atlantic Bight shelf. Intrusions were identified in about 7% of the 8500 hydrographic casts, primarily occurring during the summer (10-15% of casts). Intrusions are observed across the entire shelf, but are most common over the outer shelf, and are concentrated at the pycnocline. The percentage of intrusions increases linearly from Georges Bank (2%) to Chesapeake Bay (21%), suggesting either a north to south increase in generation or an alongshelf accumulation associated with a decay time scale of more than a month. Intrusions are typically less than 20 m thick and have a salinity anomaly of less than 0.5 psu, though 10% of the anomalies are greater than 1 psu. The thickness increases as the stratification decreases. The relationship between thickness and stratification is consistent with double-diffusive intrusions suggesting this may be the generation mechanism.

The water temperature during CMO exhibited a large seasonal variation. Depth-averaged temperatures reached a maximum (14 C) in mid September, decreased to a minimum (5 C) in mid March, and then increased to 8 C in late May. An analysis of the heat balance indicates this seasonal variation was due to roughly equal contributions from surface heating and horizontal advection. The surface heat flux contributed a seasonal variation similar to the temperature, while the horizontal advection contributed a relatively steady heat loss from September through May equivalent to a temperature decrease of about 5 C (at mid shelf). The advective component was primarily due to the low-frequency flow (time scales longer than 5 days) with similar magnitude contributions from the along-isobath and cross-isobath flows. There was not an obvious seasonal variation of salinity. Most of the low-frequency salinity variability was due to horizontal advection, primarily associated with movement of the shelf-slope front. Evaporation minus precipitation was small.

Impact/application:

The analysis of the temperature and salinity variability provides the most complete characterization of the processes influencing stratification on the New England shelf to date. A key result potentially relevant to a broad range of shelves is the importance of the cross-shelf salinity distribution to the processes influencing the stratification.

Another key result is that the heat balance over the New England shelf is not one-dimensional, that is, horizontal heat fluxes are important.

The wavelet analysis of near-inertial variability is a novel method for comparing the intrinsic frequency of near-inertial variations with the effective Coriolis frequency (affected by relative vorticity), and can be applied to other moored observations. The shift to subinertial frequencies caused by subtidal relative vorticity during CMO potentially explains the cross-shelf structure and temporal intermittency of inertial variability on the New England shelf.

Transitions: None

Related Projects:

Bottom boundary layers - We have been collaborating with Trowbridge to determine the dynamics of the bottom boundary layer and the relationship with the interior flow. We are also collaborating with Chapman (separate ONR funding) to determine whether there is a buoyancy-driven shutdown of the bottom stress as suggested in recent modeling work by Chapman and Lentz.

Hurricane response - We are collaborating with H. Seim and M. Sundermeyer on the response of the shelf to Hurricane Edouard.

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